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Sensitivity of Light-Duty Vehicle Crash Frequency per Vehicle Mile of Travel to Additional Vehicle and Driver Variables

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Executive Summary

This report examines the sensitivity of the estimated effect of mass reduction on crash frequency in the National Highway Traffic Safety Administration (NHTSA) baseline regression model to including several additional vehicle and driver characteristics. The additional variables include handling and braking capability by vehicle model, from three Consumer Reports road tests; initial vehicle purchase price and vehicle manufacturer; average household income and "bad driver" rating by vehicle model; and whether the driver was using alcohol or drugs, or was properly restrained. The three Consumer Reports road tests are associated with an unexpected increase in crash frequency, in both all crashes and single vehicle crashes with a stationary object. For this reason they were not included in the sensitivity regression models. As expected, vehicle initial purchase price, median household income, and whether the driver was wearing a seat belt are associated with statistically significant decreases in crash frequency, while whether the driver was using alcohol or drugs is associated with a statistically significant increase in crash frequency. A poor average driving record by vehicle model is associated with an expected increase in crash frequency in cars, but unexpected decreases in crash frequency in light trucks and crossover utility vehicles (CUVs)/minivans.

Including these variables, either individually or including all in the same regression model, does not change the general results of the baseline NHTSA regression model: that mass reduction is associated with an increase in crash frequency in all three types of vehicles, while footprint reduction is associated with an increase in crash frequency in cars and light trucks, but with a decrease in crash frequency in CUVs/minivans. The variable with the biggest effect is initial vehicle purchase price, which dramatically reduces the estimated increase in crash frequency in heavier-than-average cars and light trucks, and all CUVs/minivans. These results suggest that other, more subtle, differences in vehicles and their drivers account for the unexpected finding that lighter vehicles have higher crash frequencies than heavier vehicles, for all three types of vehicles.

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1. Introduction

Reducing vehicle mass is perhaps the easiest and least-costly method to reduce fuel consumption and greenhouse gas emissions from light-duty vehicles. However, the extent to which government regulations should encourage manufacturers to reduce vehicle mass depends on what effect, if any, light-weighting vehicles is expected to have on societal safety. As part of an interagency analysis effort between the National Highway Traffic Safety Administration (NHTSA), the Environmental Protection Agency (EPA), and the Department of Energy (DOE), Lawrence Berkeley National Laboratory (LBNL) has been examining the relationship between vehicle mass and size and U.S. societal fatality and casualty risk, using historical data on recent vehicle designs. This research effort informs the agencies on the extent to which vehicle mass can be reduced in order to meet fuel economy and greenhouse gas emissions standards, without compromising the safety of road users.

In 2012 NHTSA updated its 2003 and 2010 logistic regression analyses of the effect a reduction in light-duty vehicle mass has on US societal fatality risk[1] per vehicle mile of travel (VMT; Kahane 2012); the 2012 analysis is the most thorough investigation of this issue to date. In 2012 LBNL completed two studies that replicated NHTSA's analysis of fatality risk per VMT (Wenzel 2012a) and analyzed the relationship between mass reduction and the two components of risk per VMT, crashes per VMT (or crash frequency) and risk once a crash has occurred (or crashworthiness; Wenzel 2012b).

In its analyses of the relationship between vehicle mass and fatality risk, NHTSA has noted that crash frequency tends to increase as vehicle mass decreases (Kahane 2012). This runs counter to the expectation that lighter, and perhaps smaller, vehicles have better handling and shorter braking distances, and thus should be able to avoid crashes that heavier vehicles cannot. NHTSA has speculated that additional differences in who drives lighter vehicles, other than their age and gender, and how they are driven, may explain this somewhat unexpected result. LBNL's analysis of 13-state casualty risk[2] per crash (Wenzel 2012b), as well as Dynamic Research Institute (DRI 2012) and LBNL (Wenzel 2013) analyses of US fatalities per police-reported crash using a simultaneous two-stage regression model, confirms this phenomenon; vehicles of lower mass are associated with increased crash frequency for all three types of vehicles, with larger increases in crash frequency for lighter-than-average cars or light trucks. It is important to understand this phenomenon because the LBNL and DRI analyses indicate that any increases in risk per VMT associated with mass reduction are the result of mass reduction's association with crash frequency and not risk once a crash has occurred (crashworthiness/compatibility).

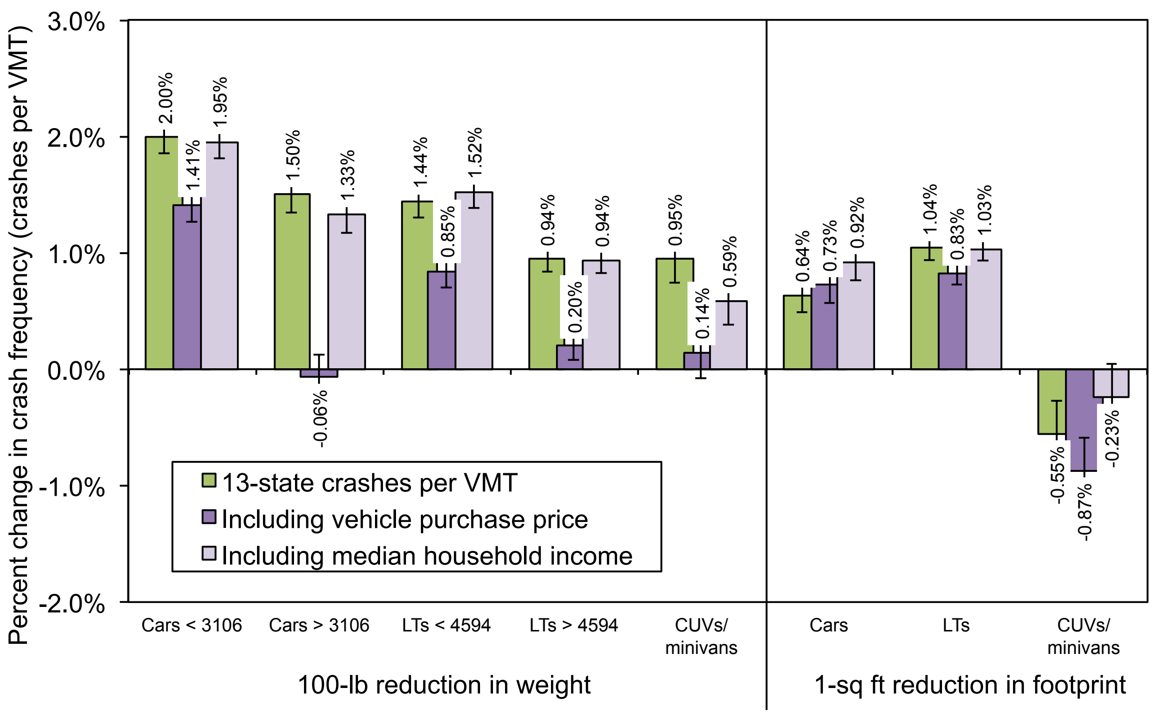
Mass reduction appears to increase crash frequency (crashes per VMT), but reduce risk per crash; the net effect is a small increase (and in some cases a small decrease) in risk per VMT. NHTSA, LBNL, and DRI suspect that a combination of vehicle design (other than mass, footprint, or safety features installed) and driver behavior (other than age and gender) may influence the relationship between reduced mass and increased crash frequency. Vehicle design may influence both crash frequency and risk per crash; however, driver behavior most likely

[1] Societal fatality risk includes the risk to both the occupants of the case vehicle as well as any crash partner or pedestrians.
[2] Casualty risk includes the risk of fatality or severe/incapacitating injury.

only influences crash frequency. Handling and braking test results should account for the vehicle design influence on crash frequency; initial vehicle purchase price may account for the influence of vehicle design on both crash frequency and risk per crash. Alcohol/drug use, poor or risky driving behavior, driver income, and seat belt use are likely to influence driver behavior. Adding these variables to the regression model may change the estimated relationship between vehicle mass and crash frequency.

In its 2012 Phase 2 report (Wenzel 2012b), LBNL found that adding vehicle purchase price to the regression model substantially reduced the estimated increase in crash frequency from mass reduction for all five vehicle types (as seen in Figure 1). Mass reduction is associated with a much smaller increase in crash frequency for lighter-than-average cars and light trucks, and small, not-statistically significant increases in crash frequency for heavier-than-average cars and light trucks, and CUVs/minivans. On the other hand, adding median household income has essentially no effect on the estimated increase in crash frequency from mass reduction. These results suggest that vehicle parameters may be influencing the somewhat unexpected increase in crash frequency from mass reduction.

Figure 1. Estimated effect of mass or footprint reduction on 13-state crashes per VMT, after accounting for vehicle purchase price or median household income, by vehicle type



This report examines the sensitivity of the estimated relationship between mass or footprint reduction and crash frequency to the addition of several variables to account for differences in vehicle models, and how their owners drive those models. We first examine the sensitivity to adding the results of vehicle braking and handling tests conducted by Consumer Reports. Then we examine the sensitivity to two other vehicle variables and four driver behavior variables.

2. Estimated effect of accounting for braking/handling

This section examines what effect vehicle braking and handling characteristics have on the relationship between mass reduction and crash frequency. Consumer Reports provided EPA a database of braking and handling test results for 491 vehicles, from model years 2000 to 2007. Section 2.1 report summarizes the data provided by Consumer Reports; the relationships between the test results and vehicle weight and crash frequency, by vehicle make and model, are presented in Sections 2.2 and 2.3, respectively. Section 2.4 tests the effect of including three of the braking and handling test results in the logistic regression model estimating the effect of mass reduction on crash frequency.

2.1. Summary of Consumer Reports test results

The data provided by Consumer Reports included curb weight, as well as the results from 13 handling and braking tests:

Table 1. Thirteen braking and handling tests conducted by *Consumer Reports*

Test	Measure
Track handling score, steering feel	1 to 5 rating
Track handling score, controllability	1 to 5 rating
Acceleration time from 0 to 30 mph	seconds
Acceleration time from 0 to 60 mph	seconds
Acceleration time from 45 to 60 mph	seconds
Time to complete quarter mile	seconds
Speed to complete quarter mile	mph
Maximum speed to complete emergency avoidance maneuver	mph
Confidence score during emergency avoidance maneuver	1 to 5 rating
Braking distance on dry pavement	feet
Braking distance on wet pavement	feet
Routine handling rating	1 to 5 rating
Turning circle	feet

The tests were performed on 263 distinct vehicle models; multiple model years were tested for some models, while different versions of some models from the same model year were tested. The left panel of Table 2 shows the distribution of tests by model; nine different model years were tested for two models, while seven model years were tested for another two models. The right panel of Table 2 shows the distribution of different versions of the same model year and model; four different versions of a MY06 Honda Civic were tested, while three different versions of a MY02 Subaru Impreza and a MY07 Camry were tested.

Table 3 shows six test results (steering feel rating, controllability rating, 0 to 60 acceleration, highest avoidance maneuver speed, dry braking distance, and routine handling rating) for seven models that had at least six individual vehicles tested. Figures 2 through 4 show graphically the range in results for the highest avoidance maneuver speed, dry braking distance, and routine handling rating tests for these seven models. The range in test results is somewhat troublesome, as it implies that the Consumer Reports test results are not highly repeatable.

Table 2. Consumer Reports tests by vehicle model, and by vehicle MY and model

Number tested	Tests by vehicle model		Tests by vehicle MY and model	
	Vehicles	Tests	Vehicles	Tests
1	126	126	393	393
2	88	176	44	88
3	29	87	2	6
4	13	52	1	4
6	3	18		
7	2	14		
9	2	18		
Total	263	491	440	491

Table 3. Consumer Reports test results for seven models with multiple model years and versions tested

MY	Model	Steer-ing feel (1 to 5)	Control-lability (1 to 5)	0-60 mph accel-eration (sec.)	Man-euver speed (mph)	Dry brak-ing 60-0 mph (ft.)	Rou-tine hand-ling (1 to 5)	Tested version
2000	Ford Focus	4.1	4.4	10.8	52.0	136	4.4	SE 2.0L 4 4AT
2000	Ford Focus	4.2	4.3	9.9	52.8	137	4.3	ZTS 2.0L 4 4AT
2002	Ford Focus	4.7	4.8	8.4	55.5	126	4.7	SVT 2.0L 4 6MT
2002	Ford Focus	4.3	4.2	10.6	52.0	137	4.5	ZX5 2.0L 4 4AT
2005	Ford Focus	4.4	4.1	10.1	52.8	128	4.5	ZX4 SES 2.0L 4 4AT
2006	Ford Focus	4.0	3.9	8.6	53.5	149	4.3	ZX3 S 2.0L 4 5MT
2006	Ford Focus	4.2	3.7	8.0	52.8	143	4.6	ZX4 ST 2.3L 4 5MT
2000	Honda Accord	3.6	3.8	8.0	50.5	141	4.0	EX 3.0L V6 4AT
2002	Honda Accord	3.7	3.7	10.4	49.8	134	3.8	EX 2.4L 4 4AT
2003	Honda Accord	3.6	3.4	9.0	50.3	144	4.2	EX 2.4L 4 5AT
2003	Honda Accord	3.9	3.6	7.4	51.0	145	4.1	EX 3.0L V6 5AT
2005	Honda Accord	3.4	3.6	6.9	52.0	130	3.8	Hybrid 3.0L V6 hybrid 5AT
2006	Honda Accord	3.8	3.9	7.3	50.3	142	4.2	EX 3.0L V6 5AT
2001	Honda Civic	3.9	4.0	10.3	52.5	134	4.0	EX 1.7L 4 4AT
2002	Honda Civic	3.5	3.7	9.0	53.0	138	4.0	Si 2.0L 4 5MT
2003	Honda Civic	3.5	3.6	13.4	50.8	134	3.8	Hybrid 1.3L 4 hybrid CVT
2005	Honda Civic	3.4	2.9	10.5	50.0	128	3.9	EX 1.7L 4 4AT
2006	Honda Civic	3.7	3.9	10.1	53.5	136	4.1	EX 1.8L 4 5AT
2006	Honda Civic	3.7	3.9	8.6	53.5	136	4.1	EX 1.8L 4 5MT
2006	Honda Civic	3.5	3.8	11.7	52.3	137	3.7	Hybrid 1.3L 4 hybrid CVT
2006	Honda Civic	3.5	4.1	7.0	54.5	132	4.3	Civic Si 2.0L 4 6MT
2007	Honda Civic	3.1	3.7	11.6	51.3	143	3.7	Civic GX 1.8L 4 5AT

Table 3 (continued). Consumer Reports test results for seven models with multiple model years and versions tested

2000	Nissan Altima	3.4	3.8	9.8	51.3	144	3.5	GXE 2.4L 4 4AT
2002	Nissan Altima	3.3	3.7	9.0	50.3	144	3.9	2.5 S 2.5L 4 4AT
2002	Nissan Altima	3.4	4.1	7.1	51.3	128	4.0	3.5 SE 3.5L V6 4AT
2005	Nissan Altima	3.1	3.4	8.9	49.3	144	3.9	2.5 S 2.5L 4 4AT
2007	Nissan Altima	3.7	3.7	8.1	51.3	134	4.0	2.5 S 2.5L 4 CVT
2007	Nissan Altima	4.1	4.1	6.4	52.3	136	4.1	3.5 SE 3.5L V6 CVT
2002	Subaru Impreza	4.0	4.1	10.1	50.8	138	4.4	2.5 RS 2.5L 4 4AT
2002	Subaru Impreza	3.8	3.7	10.5	50.0	138	4.2	Outback Sport 2.5L 4 4AT
2002	Subaru Impreza	4.1	4.3	6.2	51.0	136	4.6	WRX 2.0L 4 turbo 5MT
2004	Subaru Impreza	4.4	4.8	5.2	53.5	123	4.8	WRX STi 2.5L 4 turbo 6MT
2006	Subaru Impreza	3.7	3.7	10.3	51.5	134	4.3	2.5i 2.5L 4 4AT
2006	Subaru Impreza	4.0	3.4	6.0	52.5	136	4.6	WRX TR 2.5L 4 turbo 5MT
2000	Toyota Camry	3.0	3.3	8.0	50.0	134	3.7	LE 3.0L V6 4AT
2002	Toyota Camry	3.2	3.3	9.8	50.0	148	3.6	LE 2.4L 4 4AT
2002	Toyota Camry	3.3	3.9	8.7	50.3	128	3.7	XLE 3.0L V6 4AT
2005	Toyota Camry	3.2	3.0	9.7	48.5	147	3.6	LE 2.4L 4 5AT
2007	Toyota Camry	2.9	3.7	8.5	49.8	145	3.6	Hybrid 2.4L 4 hybrid CVT
2007	Toyota Camry	3.2	3.5	9.6	48.5	139	3.7	LE 2.4L 4 5AT
2007	Toyota Camry	3.0	3.7	7.1	50.0	137	3.7	XLE 3.5L V6 6AT
2000	VW Passat	3.7	4.0	9.7	51.8	140	4.2	GLS 1.8L 4 turbo 5AT
2000	VW Passat	3.9	3.9	7.8	52.3	138	4.2	GLS 2.8L V6 5AT
2001	VW Passat	3.9	4.1	10.0	51.0	131	4.2	GLX 2.8L V6 5AT
2002	VW Passat	4.0	3.8	9.0	52.3	142	4.1	GLS 1.8L 4 turbo 5AT
2003	VW Passat	3.9	3.8	8.8	54.3	136	4.2	GLX 2.8L V6 5AT
2004	VW Passat	4.0	4.0	11.5	51.3	137	3.8	GLS TDI 2.0L 4 TDI 5AT
2006	VW Passat	4.0	4.0	7.7	51.8	135	4.1	2.0T 2.0L 4 turbo 6AT
2006	VW Passat	3.9	3.9	6.8	53.3	135	4.1	3.6 3.6L V6 6AT
2007	VW Passat	3.9	3.9	7.0	50.5	138	4.1	3.6 3.6L V6 6AT

Figure 2. Consumer Reports average avoidance maneuver speed by model year, selected models

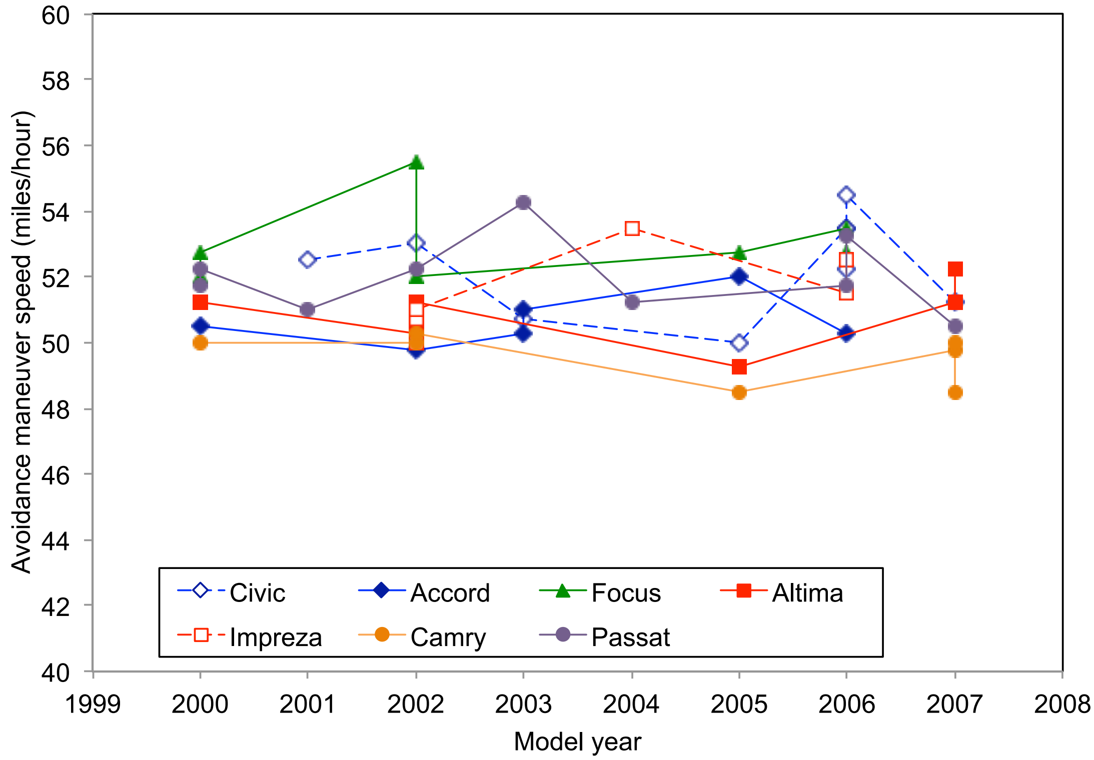


Figure 3. Consumer Reports dry braking distance by model year, selected models

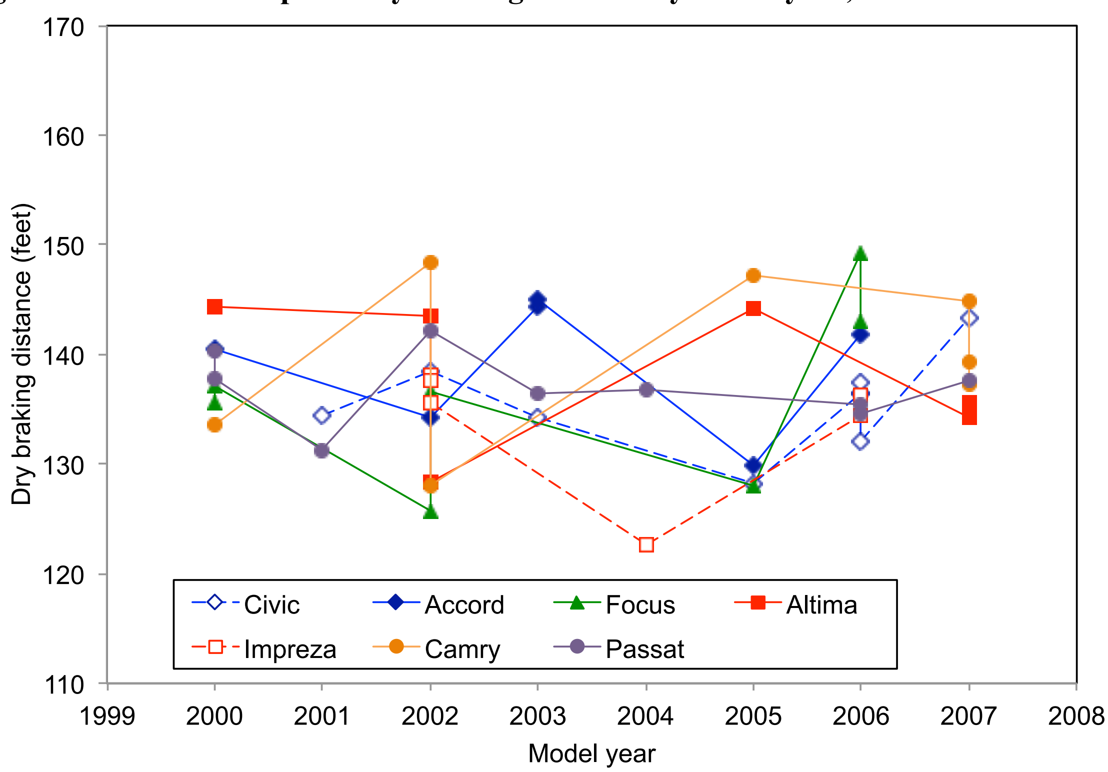


Figure 4. Consumer Reports routine handling rating by model year, selected models

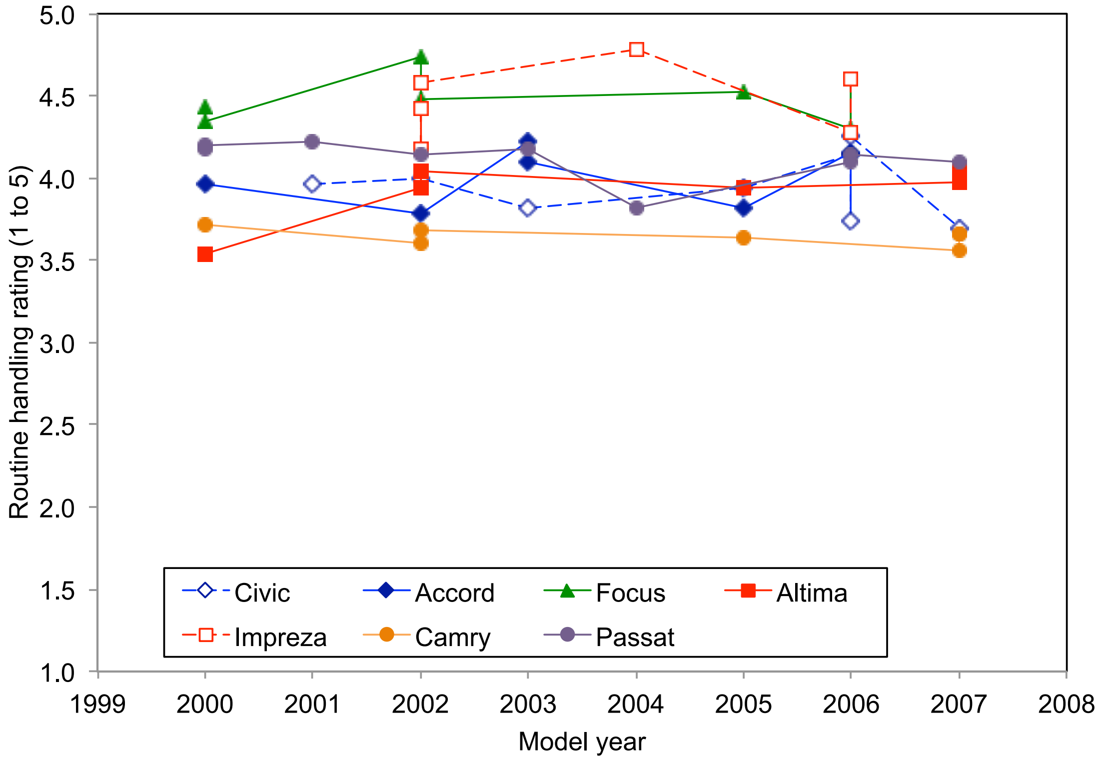


Table 4 shows suspicious results for the BMW X5 CUV, which has a steering feel, controllability, and maneuver speed confidence rating of 1.0 for the 2003 model year, but much higher ratings for the 2000, 2005, and 2007 model years.

Table 4. Suspect Consumer Reports test results for BMW X5

MY	Model	Steering feel (1 to 5)	Control-lability (1 to 5)	Maneuver speed (mph)	Maneuver speed confidence (1 to 5)	Tested version
2000	BMW X5	4.0	4.1	51.3	4.5	4.4i 4.4L V8 5AT
2003	BMW X5	1.0	1.0	50.3	1.0	3.0i 3.0L 6 5AT
2005	BMW X5	4.1	4.0	51.0	2.5	3.0i 3.0L 6 5AT
2007	BMW X5	3.9	3.5	52.5	3.7	3.0si 3.0L 6 6AT

Table 5 shows the average results for the thirteen Consumer Reports tests by vehicle type. Because Consumer Reports did not report whether the tested car had two or four doors, we separate tests of 17 “sporty” cars from other cars. Because there were few pickups tested, we combined all 23 tests of pickups into a single category.

The vehicle type with the best average result for each test is shown in green, while the type with the worst average result is shown in red. Table 4 indicates that sporty cars have the best results in each of the thirteen tests: the lowest acceleration and quarter-mile times, braking distances, and turning circle radius, and the highest ratings for steering, controllability, avoidance maneuver confidence, and routine handling, and the highest quarter-mile and avoidance maneuver speed. On the other hand, either SUVs, minivans, or pickups have the worst average test results, depending on the specific test.

Table 5. Average Consumer Reports test results by vehicle type

Test	Sporty cars	Cars	Pickups	SUVs	CUVs	Mini-vans
Number tested	17	289	23	48	92	22
Steering feel rating	4.1	3.5	2.6	2.5	3.2	3.0
Controllability rating	4.3	3.7	2.8	2.7	3.3	3.2
Acceleration time, 0 to 30 mph	2.2	3.2	3.1	3.2	3.3	3.4
Acceleration time, 0 to 60 mph	5.6	8.6	8.7	9.2	9.1	9.6
Acceleration time, 45 to 60 mph	3.8	5.5	5.7	6.1	5.8	6.1
Quarter mile time	14.1	16.6	16.7	17.1	17.0	17.4
Quarter-mile speed	102.3	86.3	83.4	81.9	83.3	81.8
Max. avoidance maneuver speed	55.1	51.5	46.7	46.5	49.2	47.9
Avoidance maneuver confidence	4.3	3.7	3.0	2.7	3.2	3.4
Dry braking distance	123.3	136.6	149.3	146.0	137.9	140.5
Wet braking distance	134.3	149.0	173.9	164.7	151.4	153.2
Routine handling rating	4.4	3.9	2.9	2.9	3.7	3.4
Turning circle radius	37.8	38.8	47.8	41.6	40.0	41.5

Results in green denote best average rating by vehicle type, results in red worst average rating by vehicle type.

2.2. Relationship between vehicle weight and Consumer Reports test results

Table 6 shows the relationship between the 13 Consumer Reports test results and vehicle curb weight, as reported by Consumer Reports. If lighter vehicles have better handling and braking characteristics than heavier vehicles, we would expect that handling ratings and quarter-mile and maneuver speeds would decrease with increasing weight, while acceleration times, quarter-mile time, braking distances, and turning circle radius would increase with increasing weight. Instances in Table 6 that meet the expected relationship between vehicle weight and the Consumer Reports test results are shown in green, while instances that are unexpected are shown in red. Table 6 indicates that lighter vehicles are not associated with shorter acceleration times, for nearly all vehicle types. Similarly, shorter quarter-mile times, and faster quarter-mile speeds, are associated with increased vehicle weight. These relationships could be explained by heavier vehicles having larger, more powerful engines, which enable more rapid acceleration and higher speeds. On the other hand, avoidance maneuvers, braking distance, and handling ratings have the expected association with increased mass: handling ratings and maneuver speeds tend to decrease, while braking distances tend to increase, with increasing weight, for five of the six vehicle types. The exception is cars: cars do not have the expected relationship with increasing weight for nearly all of the thirteen Consumer Reports tests; only avoidance maneuver speeds and turning circle radius improve with increasing car weight.

Table 6. Relationship between vehicle weight and test result, by vehicle type

Test	Sporty cars	Cars	Pickups	SUVs	CUVs	Mini-vans
Steering feel rating	-0.01%	0.00%	0.00%	-0.01%	0.00%	-0.03%
Controllability rating	0.05%	0.01%	0.00%	-0.02%	0.00%	0.00%
Acceleration time, 0 to 30 mph	0.03%	-0.05%	0.00%	0.00%	-0.03%	-0.08%
Acceleration time, 0 to 60 mph	0.04%	-0.22%	-0.04%	-0.03%	-0.11%	-0.26%
Acceleration time, 45 to 60 mph	0.00%	-0.14%	-0.03%	-0.02%	-0.07%	-0.12%
Quarter mile time	0.02%	-0.15%	-0.03%	-0.02%	-0.08%	-0.17%
Quarter-mile speed	0.02%	0.92%	0.21%	0.20%	0.47%	0.78%
Max. avoidance maneuver speed	-0.24%	-0.10%	-0.16%	-0.17%	-0.08%	-0.10%
Avoidance maneuver confidence	0.02%	0.00%	0.00%	-0.03%	-0.01%	-0.05%
Dry braking distance	0.83%	-0.15%	0.94%	0.54%	0.03%	0.28%
Wet braking distance	0.52%	-0.25%	1.34%	0.62%	-0.05%	0.19%
Routine handling rating	-0.01%	0.01%	-0.02%	-0.01%	0.00%	-0.01%
Turning circle radius	0.05%	0.27%	0.26%	0.26%	0.12%	0.03%

Results in green denote expected relationship (braking/handling capability decreases with increasing mass); results in red denote unexpected relationship (braking/handling capability increases with increasing mass).

Table 7 shows the strength of the relationship between each of the thirteen Consumer Reports tests and vehicle weight; instances where the R^2 exceeds 0.30 are shown in blue in the table. Not many of the handling/braking test results are strongly correlated with weight: only 12 of the 78 relationships have an R^2 greater than 0.30, and 36 of the 78 have an R^2 of 0.05 or less.

Table 7. Correlation between vehicle weight and test result, by vehicle type

Test	Sporty cars	Cars	Pickups	SUVs	CUVs	Mini-vans
Steering feel rating	0.02	0.00	0.01	0.06	0.00	0.03
Controllability rating	0.19	0.00	0.02	0.19	0.00	0.00
Acceleration time, 0 to 30 mph	0.15	0.20	0.01	0.00	0.20	0.38
Acceleration time, 0 to 60 mph	0.04	0.32	0.10	0.04	0.23	0.34
Acceleration time, 45 to 60 mph	0.00	0.29	0.17	0.05	0.21	0.20
Quarter mile time	0.01	0.33	0.12	0.05	0.25	0.35
Quarter-mile speed	0.00	0.39	0.21	0.14	0.29	0.27
Max. avoidance maneuver speed	0.23	0.06	0.63	0.44	0.06	0.03
Avoidance maneuver confidence	0.02	0.00	0.01	0.11	0.01	0.05
Dry braking distance	0.21	0.01	0.57	0.29	0.00	0.02
Wet braking distance	0.10	0.01	0.27	0.16	0.00	0.00
Routine handling rating	0.03	0.00	0.12	0.01	0.00	0.01
Turning circle radius	0.01	0.31	0.64	0.44	0.14	0.00

Results in blue denote correlations where R^2 exceeds 0.30.

2.3. Relationship between vehicle crash frequency and Consumer Reports test results

LBNL merged the results from the 13 handling/braking tests with the crash frequencies from the 13 state crash databases. Since test results were not available by model year for vehicle makes and models, LBNL took the average test results over all makes and models for this comparison. Both two- and four-door versions of cars were given the same average test results, as Consumer Reports did not distinguish between two- and four-door cars. LBNL did not assign test results to large pickups because there were very few such vehicles in the Consumer Reports database.

Table 8 shows the relationship between each test result and crash frequency, while Table 9 shows the correlation, by vehicle model. Instances where the relationship is in the expected direction are shown in green, while instances where the relationship is in the opposite direction are shown in red. For each point increase in the steering feel or controllability rating, crash frequency per mile driven decreases for cars and minivans, as expected, but increases for pickups, SUVs, and CUVs. Overall, the relationship between handling/braking test results and crash frequency is in the expected relationship for 54 of the 78 instances; however, in 24 instances the relationship is in the opposite direction. Most of the relationships for SUVs (8 of 13 tests), CUVs (6 of 13 tests), and small pickups (5 of 13 tests) are in the unexpected direction, whereas the relationships are in the expected direction for most of the braking/handling tests for cars and minivans.

Table 9 shows the strength of the relationship between each of the thirteen handling/braking tests and crash frequency; instances where the R^2 exceeds 0.30 are shown in blue in the table. Not many of the handling/braking test results are strongly correlated with crash frequency: only 12 of the 78 relationships have an R^2 greater than 0.30. However, 8 of the 13 tests for minivans have an R^2 greater than 0.30.

Table 8. Relationship between Consumer Reports test result and crash frequency, by vehicle type

Test	2-door cars	4-door cars	Small pickups	SUVs	CUVs	Mini-vans
Steering feel rating	-78	-93	191	137	17	-151
Controllability rating	-111	-140	363	168	54	-229
Acceleration time, 0 to 30 mph	148	216	518	76	171	46
Acceleration time, 0 to 60 mph	32	70	330	73	57	52
Acceleration time, 45 to 60 mph	-5	108	312	161	50	130
Quarter mile time	60	105	445	101	87	88
Quarter-mile speed	-11	-20	-65	-23	-18	-21
Max. avoidance maneuver speed	-15	14	37	61	11	-20
Avoidance maneuver confidence	-35	-82	-334	90	63	-167
Dry braking distance	11.8	5.2	15.9	-7.1	4.8	-10.8
Wet braking distance	5.5	4.2	11.3	-6.2	-3.4	-6.3
Routine handling rating	-108	-154	190	141	-66	-234
Turning circle radius	28	-13	-14	-32	-16	22

Results in green denote expected relationship (braking/handling capability decreases with increasing crash frequency); results in red denote unexpected relationship (braking/handling capability increases with increasing crash frequency).

Table 9. Correlation between Consumer Reports test result and crash frequency, by vehicle type

Test	2-door cars	4-door cars	Small pickups	SUVs	CUVs	Mini-vans
Steering feel rating	0.03	0.05	0.01	0.04	0.00	0.48
Controllability rating	0.04	0.07	0.06	0.06	0.02	0.68
Acceleration time, 0 to 30 mph	0.04	0.15	0.05	0.01	0.11	0.02
Acceleration time, 0 to 60 mph	0.02	0.21	0.31	0.05	0.13	0.32
Acceleration time, 45 to 60 mph	0.00	0.18	0.28	0.08	0.04	0.46
Quarter mile time	0.05	0.24	0.27	0.04	0.12	0.34
Quarter-mile speed	0.07	0.30	0.30	0.07	0.11	0.53
Max. avoidance maneuver speed	0.01	0.01	0.05	0.23	0.02	0.07
Avoidance maneuver confidence	0.00	0.03	0.05	0.03	0.07	0.50
Dry braking distance	0.07	0.02	0.16	0.03	0.02	0.20
Wet braking distance	0.05	0.04	0.30	0.06	0.02	0.07
Routine handling rating	0.03	0.08	0.01	0.04	0.03	0.62
Turning circle radius	0.04	0.02	0.01	0.12	0.04	0.11

Results in blue denote correlations where R^2 exceeds 0.30.

One-vehicle crashes with objects are the type of crash most likely to be caused by a driver losing control of his or her vehicle (as opposed to two-vehicle crashes, which could be caused by the driver of the crash partner). And crashes in which no injuries were reported tend to be less severe than crashes involving injuries. Tables 10 and 11 show the relationships and correlations between the handling/braking results and the frequency of one-vehicle, non-injury crashes with objects. In general there are more instances in which the handling/braking test results have the expected relationship with the frequency of one-vehicle, non-injury crashes (68 out of 78, in Table 10) than they do will overall crash frequency (54 out of 78, in Table 8). However, Table 11 indicates that the strength of these relationships does not improve when using one-vehicle, non-injury crash frequency (R^2 greater than 0.30 for only 7 out of 78 instances in Table 11) rather than overall crash frequency (R^2 greater than 0.30 for 12 out of 78 instances in Table 9).

Table 10. Relationship between Consumer Reports test result and one-vehicle, non-injury crash frequency, by vehicle type

Test	2-door cars	4-door cars	Small pickups	SUVs	CUVs	Mini-vans
Steering feel rating	-15.5	-18.4	10.6	-5.1	-16.8	-16.3
Controllability rating	-15.6	-25.4	7.8	-6.7	-14.1	-74.9
Acceleration time, 0 to 30 mph	-1.9	16.1	194.0	13.4	38.8	9.8
Acceleration time, 0 to 60 mph	-2.4	5.7	49.9	5.1	15.3	17.3
Acceleration time, 45 to 60 mph	-14.5	8.7	35.5	18.7	24.0	37.0
Quarter mile time	-1.3	8.8	55.5	6.1	21.2	25.0
Quarter-mile speed	-0.2	-1.8	-5.6	-0.8	-3.7	-5.9
Max. avoidance maneuver speed	-4.9	-1.5	-1.3	3.3	-2.3	-18.5
Avoidance maneuver confidence	-8.9	-16.4	-64.1	-6.3	-4.0	-34.7
Dry braking distance	0.95	1.22	3.64	0.32	3.62	1.82
Wet braking distance	0.36	0.56	1.94	-0.46	0.81	-0.24
Routine handling rating	-14.1	-20.4	-7.0	-1.7	-33.6	-56.2
Turning circle radius	9.5	1.4	4.3	-1.6	1.2	6.3

Results in green denote expected relationship (braking/handling capability decreases with increasing mass); results in red denote unexpected relationship (braking/handling capability increases with increasing mass).

Table 11. Correlation between Consumer Reports test result and one-vehicle, non-injury crash frequency, by vehicle type

Test	2-door cars	4-door cars	Small pickups	SUVs	CUVs	Mini-vans
Steering feel rating	0.02	0.08	0.00	0.00	0.05	0.06
Controllability rating	0.02	0.09	0.00	0.00	0.03	0.72
Acceleration time, 0 to 30 mph	0.00	0.04	0.22	0.01	0.15	0.01
Acceleration time, 0 to 60 mph	0.00	0.06	0.22	0.01	0.25	0.36
Acceleration time, 45 to 60 mph	0.05	0.05	0.12	0.05	0.25	0.37
Quarter mile time	0.00	0.07	0.13	0.01	0.19	0.27
Quarter-mile speed	0.00	0.10	0.07	0.00	0.13	0.42
Max. avoidance maneuver speed	0.02	0.01	0.00	0.03	0.02	0.58
Avoidance maneuver confidence	0.01	0.06	0.06	0.01	0.01	0.21
Dry braking distance	0.01	0.05	0.26	0.00	0.30	0.06
Wet braking distance	0.00	0.03	0.28	0.01	0.04	0.00
Routine handling rating	0.01	0.06	0.00	0.00	0.19	0.35
Turning circle radius	0.11	0.01	0.04	0.01	0.01	0.10

2.4. Sensitivity of crash frequency regression to Consumer Reports test results

LBNL then merged results for three of the Consumer Reports tests, maximum speed achieved during the avoidance maneuver test, acceleration time from 45 to 60 mph, and dry braking distance, with the database used to estimate the effect of mass reduction on crash frequency, from LBNL's Phase 2 report. For this analysis multiple results for individual vehicle models were averaged by model year. For models that were not tested in each model year between 2001 and 2007, the test result for a previous model year was used, while the first test result was used for models that did not have a 2001 version tested. For example, Consumer Reports tested only one Dodge Stratus, from model year 2004; the results from this vehicle were applied to all Stratus from model years 2001 to 2006 (the Stratus was discontinued in model year 2007).

Table 12 compares the results of five alternative regression models estimating the effect on overall car crash frequency (crashes per vehicle mile traveled, or VMT), to NHTSA's baseline model (from LBNL Phase 2 report). For each of the models in the table, coefficients from separate regressions for each of the nine crash types are reweighted by the number of fatalities in each type of crash assuming full penetration of ESC technology; see Kahane 2012 and Wenzel 2012. The regression estimates presented here are converted from odds to probabilities, as they were in (Wenzel 2012).

The first model limits the analysis to those car models that could be matched to Consumer Reports test results; almost 90% of cars involved in crashes were matched to Consumer Reports data. Limiting the analysis to matched car models has little effect on the estimated effect of mass or footprint reduction on crash frequency. Model 2 adds MANEUVER, the maximum speed (in miles per hour) the vehicle obtained on the avoidance maneuver test; a higher value indicates better handling. Model 2 estimates that for each additional mile per hour achieved on the test, overall crash frequency increases 0.82%; this suggests that better results on this handling test increases crash frequency. Model 3 adds the ACC45TO60 test result, the time (in seconds) for the vehicle to accelerate from 45 to 60 miles per hour; here the higher the value (i.e. more time), the worse the vehicle handling in emergency situations. Model 3 suggests that for each additional second to achieve 60 miles per hour, a vehicle's crash frequency is reduced 1.80%; this suggests that faster acceleration is associated with higher crash frequency. This result is not entirely unexpected, as drivers of vehicles with faster acceleration may tend to take advantage of their vehicles' capabilities and drive them more recklessly. Model 4 includes the DRYBRAKE test result, the stopping distance (in feet) on a dry surface; a higher value for DRYBRAKE indicates that the vehicle has relatively lower braking effectiveness. Model 4 suggests that every one-foot increase in braking distance, or decrease in braking capability, is associated with a 0.12% reduction in crash frequency, which also is in the unexpected direction. Therefore for each of the three test results, an improvement in handling or braking capability is associated with a statistically-significant increase in crash frequency. Model 5 adds all three of these variables to the regression model; the signs of the estimated coefficients do not change, although the estimated effect of each is reduced from Models 2 through 4.

The estimated effect of mass or footprint reduction on crash frequency changes when one or all of the three Consumer Reports test ratings are included in the regression models; however, in each case mass or footprint reduction is associated with an increase in crash frequency, as in the the NHTSA baseline model.

Table 12. Estimated effect of mass or footprint reduction on 13-state crash frequency (crashes per VMT), under alternative regression model specifications

Variable	NHTSA baseline model (crashes per VMT)	1. Using only vehicles with CR test results	2. Including MANEUVER (max speed on avoidance maneuver test)	3. Including ACC45TO60 (sec to accelerate from 45 to 60 mph)	4. Including DRYBRAKE (stopping distance in feet on dry surface	5. Including MANEUVER, ACC45TO60, and DRYBRAKE
UNDRWT00	1.97%*	1.95%*	1.80%*	2.14%*	1.94%*	2.03%*
OVERWT00	1.34%*	1.20%*	0.99%*	1.10%*	1.12%*	0.97%*
FOOTPRNT	0.85%*	0.96%*	0.93%*	1.14%*	0.97%*	1.12%*
MANEUVER	—	—	0.82%*	—	—	0.42%*
ACC45TO60	—	—	—	-1.80%*	—	-1.58%*
DRYBRAKE	—	—	—	—	-0.12%*	-0.06%*

* statistically significant at the 95% level.
Results in red denote unexpected relationship (crash frequency increases with improved braking/handling capability)
Note: All reweight the estimated coefficients from nine regression models by crash type by the number of fatalities by type of crash after assuming full penetration of ESC technology (NHTSA baseline model). Estimates converted from odds to probabilities.

Table 13 shows the results only for crash frequency in crashes with stationary objects, which reduces the effect of the driver of another vehicle on whether a crash occurs. As in Table 12 (for all crashes) the coefficients for the three handling/braking variables in Table 13 (for only crashes with stationary objects) are not in the expected direction, and are substantially larger. For example, an increase in maximum maneuver speed is associated with a 2.65% increase, an increase in the time to reach 60 miles per hour is associated with a 3.03% decrease, and an increase in braking distance is associated with a 0.43% decrease in the likelihood of a crash with a stationary object.

As in Table 12, adding one or all of the three handling/braking variables has relatively little effect on the estimated relationship between mass reduction in lighter-than-average cars or footprint reduction and the frequency of crashes with stationary objects. However, adding one or all three of the handling/braking variables increases the beneficial effect of mass reduction in heavier-than-average cars on crash frequency with stationary objects, from a 0.17% reduction in crash frequency in the baseline model to as much as a 1.34% reduction in crash frequency in Model 5.

Table 13. Estimated effect of mass or footprint reduction on 13-state frequency of crashes with stationary objects, under alternative regression model specifications

Variable	NHTSA baseline model (crashes per VMT)	1. Using only vehicles with CR test results	2. Including MANEUVER (max speed on avoidance maneuver test)	3. Including ACC45TO60 (sec to accelerate from 45 to 60 mph)	4. Including DRYBRAKE (stopping distance in feet on dry surface	5. Including MANEUVER, ACC45TO60, and DRYBRAKE
UNDRWT00	1.18%*	1.27%*	0.80%*	1.60%*	1.22%*	1.19%*
OVERWT00	-0.17%*	-0.60%*	-1.27%*	-0.79%*	-0.89%*	-1.34%*
FOOTPRNT	2.52%*	2.82%*	2.74%*	3.12%*	2.88%*	3.02%*
MANEUVER	—	—	2.65%*	—	—	1.63%*
ACC45TO60	—	—	—	-3.03%*	—	-2.20%*
DRYBRAKE	—	—	—	—	-0.43%*	-0.27%*

* statistically significant at the 95% level.

Results in red denote unexpected relationship (crash frequency increases with improved braking/handling capability)

Note: All reweight the estimated coefficients from nine regression models by crash type by the number of fatalities by type of crash after assuming full penetration of ESC technology (NHTSA baseline model). Estimates converted from odds to probabilities.

LBNL did not extend the regression analysis including the three Consumer Reports test results to CUVs/minivans because nearly half of the CUV/minivan models could not be matched with Consumer Reports data. And the analysis was not extended to light trucks because Consumer Reports did not test any heavy-duty truck models, and did not report the drive configuration, cab or bed size of the pickup and SUV models it did test.

3. Estimated effect of accounting for other vehicle and driver characteristics

Table 14 shows the estimated effect of seven alternative regression models that test the sensitivity of the relationship between mass or footprint reduction and crash frequency to additional vehicle or driver variables. Coefficients shown in red font are statistically significant, based on the Chi-square value output by SAS.

Alternative Model 1 includes the initial purchase price, in thousands of dollars, by vehicle model, as derived from the Polk VIN decoder; this information was available for about 97% of the vehicles in the state crash databases. Table 15 indicates that average initial purchase price varies from just over $19,000 for two-door cars to over $30,000 for large pickups and all-wheel drive cars. Including initial purchase price tends to lower slightly the detrimental effect of mass reduction on crash frequency, particularly for heavier-than-average cars, which now show a slight reduction in crash frequency associated with mass reduction. The last three rows in the table indicated that crash frequency is slightly reduced for every additional $1,000 in the initial purchase price of a particular vehicle model.

Alternative Model 2 includes the average income of households that own a particular model of vehicle. The data are derived from California vehicle registration data, based on the median income in the zip code in which individual vehicles are registered, averaged over all vehicles of a given model. This information was available for about 97% of the vehicles in the state crash databases. Table 15 indicates that average household income ranges from just under $49,000 for pickups to over $58,000 for all-wheel drive cars (police cars, which are owned by government agencies located in predominantly urban zip codes, have an average "household" income of only $40,000). Model 2 suggests that including average household income by vehicle model has little effect on the estimated relationship between vehicle mass or footprint reduction and crash frequency.

Table 14. Effect of mass and footprint reduction on crash frequency, under alternative regression model specifications

Variable	Case vehicle type	NHTSA baseline model (crashes per VMT)	1. Including initial vehicle purchase price ($000s)	2. Including median household income ($000s)	3. Including 15 variables for vehicle manufacturer	4. Including average "bad driver" rating	5. Including whether driver was using alcohol or drugs	6. Including whether driver was properly using restraint	7. Including all additional variables
Mass reduction	Cars < 3106	1.97%	1.41%	1.93%	1.67%	1.94%	2.02%	1.97%	1.43%
	Cars > 3106	1.34%	-0.16%	1.16%	1.89%	1.08%	1.30%	1.39%	0.80%
	LTs < 4594	1.43%	0.84%	1.52%	1.57%	1.14%	1.35%	1.44%	0.75%
	LTs > 4594	0.93%	0.20%	0.92%	1.22%	0.75%	0.83%	0.94%	0.51%
	CUV/mvan	0.93%	0.17%	0.57%	1.67%	0.41%	0.97%	0.92%	0.69%
Footprint reduction	Cars	0.85%	0.94%	1.14%	1.09%	1.21%	0.99%	0.89%	1.48%
	LTs	1.09%	0.87%	1.08%	0.97%	1.35%	1.12%	1.09%	1.09%
	CUV/mvan	-0.53%	-0.86%	-0.21%	-0.98%	-0.04%	-0.64%	5.09%	-0.16%
Initial purchase price	Cars	—	-0.81%	—	—	—	—	—	-0.45%
	LTs	—	-1.18%	—	—	—	—	—	-1.09%
	CUV/mvan	—	-1.18%	—	—	—	—	—	-0.14%
Average household income	Cars	—	—	-0.84%	—	—	—	—	0.07%
	LTs	—	—	-0.22%	—	—	—	—	0.77%
	CUV/mvan	—	—	-0.98%	—	—	—	—	-0.85%
Bad driver rating	Cars	—	—	—	—	6.46%	—	—	6.91%
	LTs	—	—	—	—	-23.5%	—	—	-38.9%
	CUV/mvan	—	—	—	—	-9.91%	—	—	-10.0%
Driver alcohol or drug use	Cars	—	—	—	—	—	1187%	—	1050%
	LTs	—	—	—	—	—	1051%	—	914%
	CUV/mvan	—	—	—	—	—	974%	—	886%
Driver properly restrained	Cars	—	—	—	—	—	—	-14.7%	-7.27%
	LTs	—	—	—	—	—	—	-17.2%	-9.45%
	CUV/mvan	—	—	—	—	—	—	-7.34%	0.17%

Estimates in red are statistically significant at the 95% level.

Alternative Model 3 includes dummy variables for 15 vehicle makes; accounting for vehicle make does not substantively change the relationship between mass or footprint reduction and crash frequency.

Table 15. Average vehicle and driver characteristics, by vehicle type

Vehicle type	Average initial purchase price	Average household income	Average bad driver rating	Percent drivers using alcohol or drugs	Percent drivers not using restraints
2-dr cars	$19,181	$49,748	0.66	3.88%	3.64%
4-dr cars	$20,174	$49,249	0.49	2.41%	2.61%
Sporty cars	$24,870	$51,406	0.80	5.65%	4.18%
Police cars	$25,070	$40,441	0.26	0.53%	4.02%
AWD cars	$30,229	$58,517	0.52	2.79%	1.72%
Sm pickups	$24,321	$48,045	0.56	4.51%	4.19%
Lg pickups	$30,854	$48,561	0.49	3.91%	4.61%
SUVs	$29,710	$51,515	0.48	2.83%	2.60%
CUVs	$25,100	$54,574	0.36	1.83%	1.79%
Minivans	$25,555	$50,464	0.25	1.09%	1.75%
Full vans	$24,003	$49,517	0.37	1.44%	2.48%
All	$23,352	$50,033	0.49	2.76%	2.83%

NHTSA baseline regression model and alternative models exclude the vehicle types shown in red.

The average "bad driver" rating by vehicle model is added to alternative Model 4. In its 2003 report NHTSA created a "bad driver" rating variable based on whether alcohol or drugs were involved in the current crash, whether the driver had a valid license or was accused of reckless driving in the current crash, or whether the driver had a moving violation within the last three years. Table 15 shows that sporty cars have the highest average bad driver rating, 0.80, followed by 2-door cars (0.66), while minivans and police cars have an average bad driver rating of less than 0.30. In terms of individual vehicle models, the bad driver rating varies from 0.16 for Honda Odyssey to 1.08 for Lexus IS-300 and Acura CL.

We assigned the average bad driver rating to each vehicle model in the state crash cases, and included the variable in the regression models (the NHTSA and LBNL 2012 reports excluded FARS cases where drivers were suspected of alcohol or drug use, or were otherwise "bad" drivers). We only included the bad driver rating for vehicle models that had at least 50 individual vehicles in the FARS data, which accounted for about 95% of all the vehicles in the crash data an induced exposure data. Table 14 indicates that adding the bad driver rating variable does not substantively change the estimated relationship between mass or footprint reduction and crash frequency. Car crash frequency increases as bad driver rating increases; however, increasing bad driver ratings are associated with a reduction in crash frequency in light trucks and CUVs/minivans.

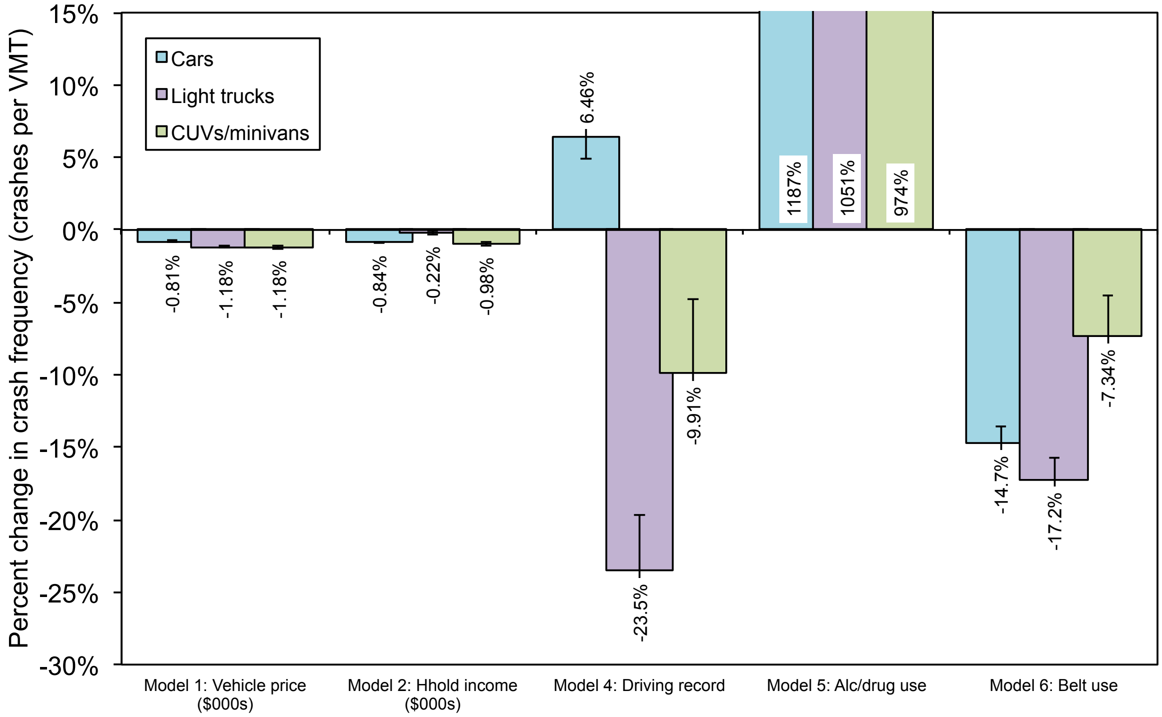
Alternative Models 5 and 6 account for whether the drivers in the state crash data cases were suspected of using alcohol or drugs, or were not wearing safety restraints, respectively, at the time of the crash. These data were reported for about 96% of the crash cases, and about 94% of the induced exposure crash cases used to estimate vehicle miles of travel. There are very few case vehicles whose driver was suspected of using alcohol or drugs, or was not wearing a safety restraint. Only 2.76% of drivers in all crashes, and only 88 of over 127,000 drivers in the induced exposure cases (0.07%), were suspected of using alcohol or drugs, and only 2.83% of drivers in all crashes, and only 722 of over 134,000 drivers in the induced exposure cases (0.53%), were not wearing their restraints. Table 15 indicates that suspected alcohol/drug use was highest in small pickups (4.51%) and lowest in police cars (0.53%) and minivans (1.09%); drivers in sporty cars, police cars, and pickups were most likely not to use restraints (over 4%), while drivers in minivans, CUVs, and all-wheel driver cars were least likely not to use restraints (under 2%).

The last rows of Table 14 indicate that crash frequency increases dramatically if the driver was using alcohol or drugs, and decrease substantially if the driver was properly using his or her restraint. Adding either of these variables to the regression models has little effect on the estimated relationship between mass or footprint reduction on crash frequency, with one exception: adding restraint use changes the estimated effect of footprint reduction in CUVs/minivans from a slight decrease in crash frequency in the NHTSA baseline model (0.53%) to a large increase in crash frequency (5.09%).

Alternative Model 7 includes all of the additional variables (initial vehicle purchase price, average household income, 15 vehicle makes, average bad driver rating, driver alcohol/drug use, and driver restraint use) in one regression model. Including all of the variables reduces the number of crash cases by about 15%. Because of the large number of control variables added to the model (20 additional variables, for a total of 63), alternative Model 7 excludes control variables that are not statistically-significant. While including all of the additional variables in Model 7 reduces the estimated effect of mass or footprint reduction on crash frequency in many cases, in every one of the eight cases the sign of the coefficient is the same as in the NHTSA baseline model.

For the most part, the estimated effect of the five additional vehicle and driver variables on crash frequency is similar when all five variables are included in the Model 7 as when only one of the five is included. However, there are some exceptions: initial vehicle purchase price gets very small for CUVs in the Model 7 (from -1.18% in Model 1 to -0.14% in Model 7); average household income changes sign for cars (from -0.84% in Model 2 to 0.07% in Model 7) and light trucks (from -0.22% in Model 2 to 0.77% in Model 7); the estimated beneficial effect of restraint use is much lower for cars (from -14.7% in Model 6 to -7.27% in Model 7) and light trucks (from -17.2% in Model 6 to -9.45% in Model 7), and becomes insignificant for CUVs (from -7.34% in Model 6 to 0.17% in Model 7).
Figure 5 shows graphically the estimated effect of adding each of the five additional variables listed in Table 14 on the change in crash frequency estimated in the baseline model, by vehicle type. Again, Figure 5 suggests that increasing vehicle price, household income, and driver seat belt use are each associated with a reduction in crash frequency, while driver alcohol/drug use is associated with a very large increase in crash frequency, in all three vehicle types. A poor driving record is associated with an increase in crash frequency in cars, but a decrease in crash frequency in light trucks and CUVs/minivans.

Figure 5. Estimated effect of individually adding five additional variables on the change in crash frequency estimated in baseline model, by vehicle type



Figures 6 through 8 graphically show the estimated effect of adding the five additional variables listed in Table 14, individually and cumulatively, on the estimated effect of mass or footprint reduction on crash frequency, for cars, light trucks, and CUVs/minivans, respectively. The last columns in the figure ("All 5 + Makes") represent the estimated effect of Model 7 shown in Table 14 (adding all five of the additional variables, as well as 15 vehicle manufacturer variables, and including only those variables that are statistically-significant).

Table 16 compares all of the control variables estimated by the baseline model with those estimated by Model 7. Crash frequency decreases for SUVs (from an 0.80% decrease to a 3.76% decrease), heavy-duty pickups (from a 3.4% decrease to a 10.5% decrease), and trucks with secondary energy absorbing structures (BLOCKER2; from a 0.69% decrease to a 4.55% decrease) in Model 7 compared to the baseline model. Including all of the five additional vehicle and driver variables in Model 7: makes ABS less effective in reducing crashes in cars (from a 6.14% reduction to a 1.58% increase in crash frequency) and CUVs/minivans (from a 19.6% reduction to 9.78% reduction in crash frequency); makes ESC less effective in reducing crashes

Figure 6. Estimated effect of adding five additional variables on the estimated change in mass or footprint reduction on crash frequency, cars

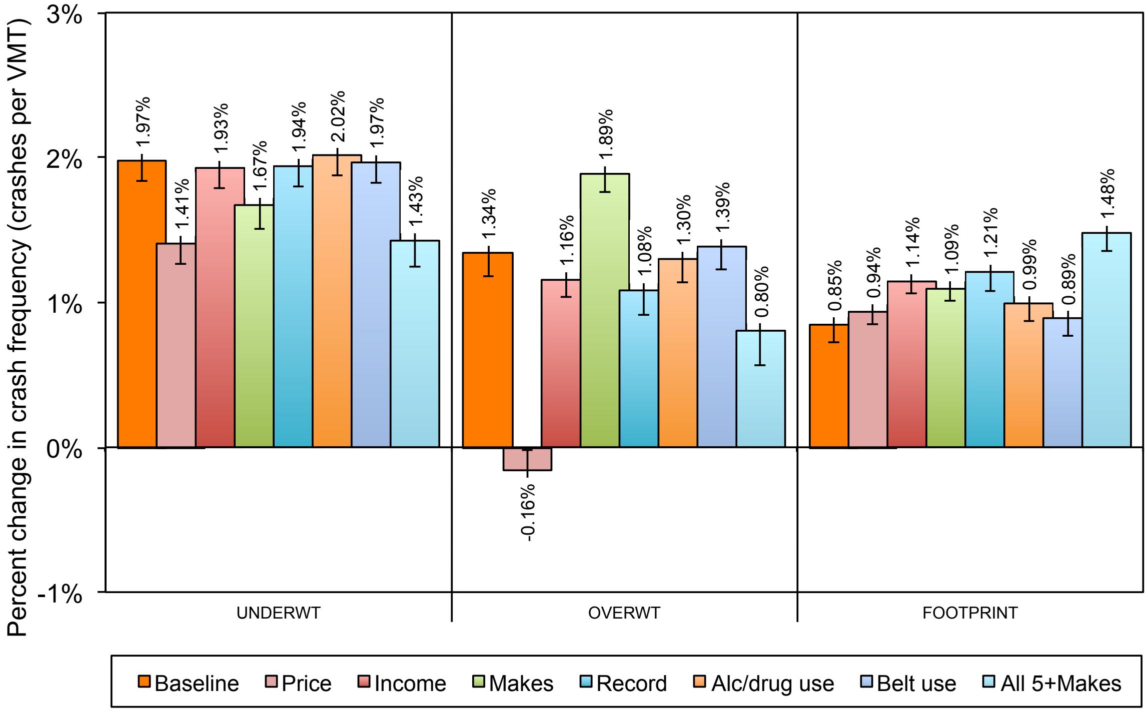


Figure 7. Estimated effect of adding five additional variables on the estimated change in mass or footprint reduction on crash frequency, light trucks

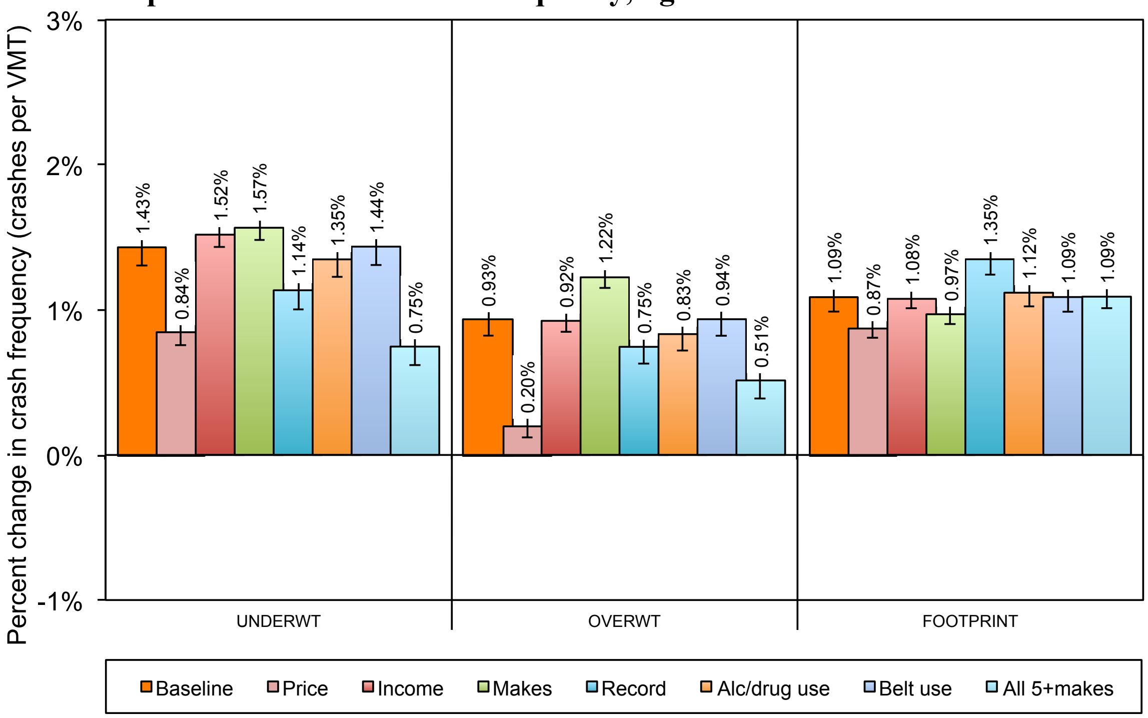
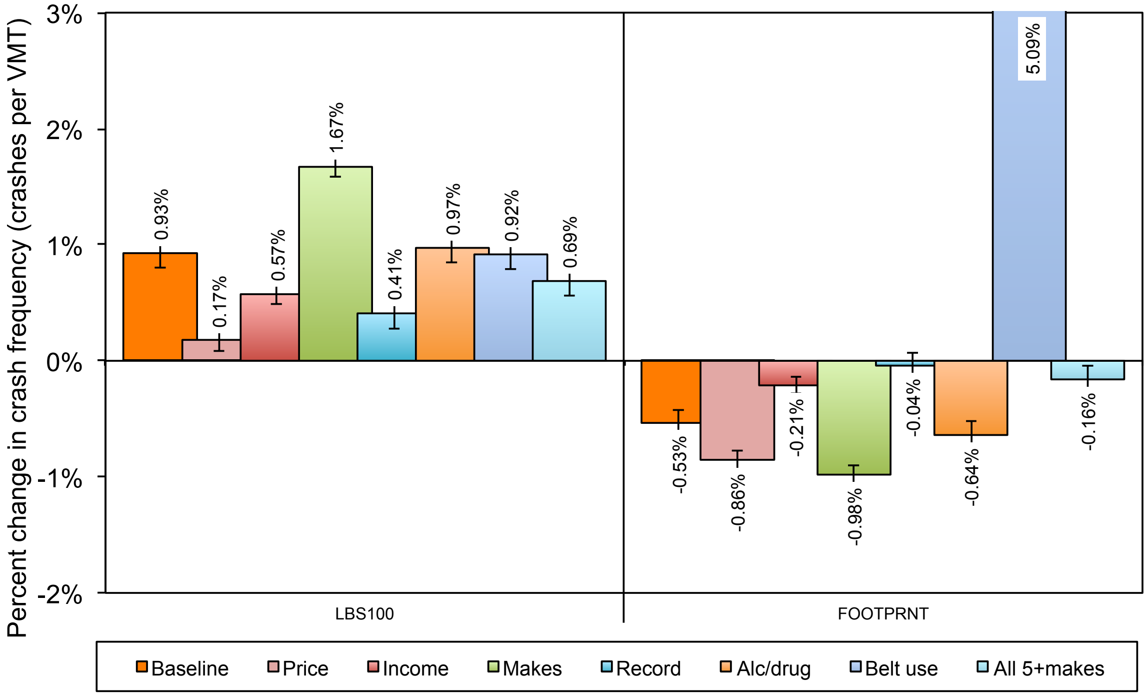


Figure 8. Estimated effect of adding five additional variables on the estimated change in mass or footprint reduction on crash frequency, CUVs/minivans



in all three types of vehicles, especially light trucks (from a 15.7% reduction to a 5.26% reduction); makes AWD more dangerous in CUVs/minivans (from a 10.7% increase to a 16.4% increase in crash frequency); and makes driving at night less dangerous in all three types of vehicles (from a 25% to 38% increase to a 18% to 24% increase in crash frequency, depending on vehicle type). It is unclear why the estimated effect of crash frequency in Maryland changes sign for all three vehicle types when the five additional vehicle and driver variables are added.

The 15 dummy variables for vehicle makes show some interesting results. VW, BMW, Volvo, Nissan, Honda and Mercedes-Benz cars tend to have lower-than-average crash frequency, while Kia, Hyundai, and Mazda cars tend to have higher-than-average crash frequency. Toyota, Mercedes Benz, and Nissan light trucks tend to have lower-than-average crash frequency, while Mazda, Kia and Mitsubishi tend to have higher-than-average crash frequency. And Subaru, BMW, and Other CUVs/minivans tend to have lower-than-average crash frequency, while Kia, Mitsubishi, Hyundai, and Mazda CUVs/minivans tend to have higher-than-average crash frequency.

4. Conclusions

This report examines the sensitivity of the estimated relationship between mass or footprint reduction and crash frequency to the addition of several variables to account for differences in vehicle models, and how their owners drive those models. We examined the results of three vehicle braking and handling tests conducted by Consumer Reports: the maximum speed achieved during the avoidance maneuver test, acceleration time from 45 to 60 mph, and dry braking distance.

Table 16. Estimated effect of variables on 13-state crash frequency per VMT, by vehicle type

	NHTSA baseline			Including additional vehicle and driver variables		
Variable	Cars	LTs	CUVs	Cars	LTs	CUVs
UNDERWT	1.97%	1.43%	—	1.43%	0.75%	—
OVERWT	1.34%	0.93%	—	0.80%	0.51%	—
LBS100	—	—	0.93%	—	—	0.69%
FOOTPRINT	0.85%	1.09%	-0.53%	1.48%	1.09%	-0.16%
TWODOOR	4.98%	—	—	4.45%	—	—
SUV	—	-0.80%	—	—	-3.76%	—
HD	—	-3.40%	—	—	-10.5%	—
BLOCKER1	—	-0.21%	—	—	-1.65%	—
BLOCKER2	—	-0.69%	—	—	-4.55%	—
MINIVAN	—		2.68%	—		1.43%
ROLLCURT	-1.93%	—	-0.89%	-3.66%	—	-1.29%
CURTAIN	-0.10%	—	-3.40%	1.10%	—	2.54%
COMBO	2.36%	—	-0.37%	0.77%	—	2.94%
TORSO	-5.43%	—	-4.81%	-2.14%	—	-2.58%
ABS	-6.14%	—	-19.6%	1.58%	—	-9.78%
ESC	-16.8%	-15.7%	-1.20%	-14.3%	-5.26%	0.39%
AWD	—	44.9%	10.7%	—	43.4%	16.4%
VEHAGE	0.43%	-0.02%	1.45%	0.62%	0.20%	1.96%
BRANDNEW	6.24%	0.84%	0.38%	5.29%	-0.99%	-0.19%
DRVMALE	6.43%	-0.95%	1.90%	4.60%	-1.82%	0.93%
M14_30	4.41%	3.83%	5.11%	4.53%	3.75%	5.23%
M30_50	0.35%	0.39%	0.18%	0.20%	0.32%	0.05%
M50_70	0.16%	0.33%	0.61%	0.17%	0.42%	0.60%
M70_96	3.98%	4.42%	3.40%	3.97%	4.41%	3.59%
F14_30	3.49%	3.57%	3.62%	3.56%	3.45%	3.68%
F30_50	-0.04%	0.01%	-0.01%	-0.12%	0.02%	-0.09%
F50_70	0.71%	0.93%	1.10%	0.74%	1.07%	1.08%
F70_96	4.37%	3.38%	3.43%	4.28%	2.15%	3.73%
NITE	32.4%	37.8%	25.2%	22.0%	23.9%	18.4%
RURAL	21.3%	20.3%	15.6%	19.7%	18.8%	13.8%
SPDLIM55	62.1%	41.9%	34.5%	62.0%	41.9%	35.2%
CY2002	-8.09%	-9.70%	-10.9%	-7.37%	-8.70%	-7.80%
CY2003	-6.03%	-3.12%	-5.21%	-5.61%	-3.32%	-2.47%
CY2004	-4.01%	-1.93%	-3.01%	-3.41%	-1.60%	-0.42%
CY2005	-1.64%	-0.16%	-0.13%	-0.77%	0.67%	1.04%
CY2007	3.89%	2.72%	3.58%	3.39%	1.57%	2.15%
CY2008	3.96%	2.01%	5.28%	2.67%	1.13%	3.77%
AL	143%	91.5%	130%	152%	104%	138%
KS	63.1%	38.4%	58.8%	70.4%	46.9%	61.5%
KY	157%	134%	198%	170%	152%	213%
MD	-1.84%	-14.2%	-4.90%	28.0%	11.1%	17.0%
MI	97.3%	62.1%	78.0%	102%	67.8%	80.6%
MO	98.5%	59.8%	89.9%	109%	70.4%	99.9%
NE	85.4%	55.4%	65.4%	86.8%	54.9%	62.7%
NJ	85.0%	66.9%	79.1%	102%	82.3%	87.9%
PA	-28.2%	-25.5%	-25.3%	-28.9%	-27.0%	—
WA	23.4%	31.3%	45.1%	40.8%	50.7%	63.0%
WI	49.5%	34.8%	36.8%	43.5%	32.3%	31.4%
WY	138%	32.4%	96.2%	158%	43.8%	118%

Table 16. Estimated effect of variables on 13-state crash frequency per VMT, by vehicle type (cont.)

Variable	NHTSA baseline			Including additional vehicle and driver variables		
	Cars	LTs	CUVs	Cars	LTs	CUVs
CHRYS	—	—	—	1.58%	12.3%	7.95%
FORD	—	—	—	3.30%	15.8%	2.89%
TOYOTA	—	—	—	-0.36%	-18.0%	8.54%
HONDA	—	—	—	-4.12%	—	6.07%
NISSAN	—	—	—	-7.23%	-10.0%	0.05%
HYUNDAI	—	—	—	13.9%	—	15.8%
MITSU	—	—	—	0.75%	19.9%	25.8%
VW	—	—	—	-20.1%	—	—
KIA	—	—	—	19.3%	23.6%	26.1%
MAZDA	—	—	—	9.54%	25.5%	10.1%
BMW	—	—	—	-18.1%	—	-13.1%
SUBARU	—	—	—	—	—	-17.3%
MBZ	—	—	—	-2.54%	-11.3%	—
VOLVO	—	—	—	-10.7%	—	—
OTHER	—	—	—	—	9.98%	-25.0%
PRICE000	—	—	—	-0.45%	-1.09%	-0.14%
INC000	—	—	—	0.07%	0.77%	-0.85%
BAD_DRV	—	—	—	6.91%	-38.9%	-10.0%
ALC_DRUG	—	—	—	1050%	914%	886%
RESTUSE	—	—	—	-7.27%	-9.45%	0.17%

Estimates in red are statistically significant at the 95% level.

When these three test results are added to the LBNL baseline regression model of the number of crashes per mile of vehicle travel in cars, none of the three handling/braking variables are associated to have the expected effect on crash frequency. In other words, an increase in maximum maneuver speed, the time to reach 60 miles per hour, or braking distance on dry pavement in cars, either separately or combined, is associated with a decrease in the likelihood of a crash, of any type or with a stationary object.

Adding one or all of the three handling/braking variables has relatively little effect on the estimated relationship between mass or footprint reduction in cars and crash frequency in all types of crashes. However, the beneficial effect of mass reduction in heavier-than-average cars on crash frequency with stationary objects is expected to increase, from a 0.17% reduction in crash frequency in the baseline model to as much as a 1.34% reduction in crash frequency when all three variables are included.

LBNL did not extend the regression analysis including the three Consumer Reports test results to CUVs/minivans because nearly half of the CUV/minivan models could not be matched with Consumer Reports data, or to light trucks because Consumer Reports did not test any heavy-duty truck models, and did not report the drive configuration, cab or bed size of the pickup and SUV models it did test. Because Consumer Reports test results could be matched to vehicle models representing only 40% of all cars, 22% of all CUVs and minivans, and essentially none of all light trucks, adding the braking/handling test results can only provide limited insight into how a vehicle's braking and handling characteristics affect the frequency it is involved in crashes.

Adding two variables to account for differences in vehicle models, and four variables to account for differences in driver characteristics and behavior, to the baseline model of crashes per mile of vehicle travel for the most part achieved the expected results. Increasing vehicle price, household income, and driver seat belt use are each associated with a reduction in crash frequency, while driver alcohol/drug use is associated with a very large increase in crash frequency, in all three vehicle types. However, while a poor driving record is associated with an increase in crash frequency in cars, it is associated with a decrease in crash frequency in light trucks and CUVs/minivans.

Including these variables, either individually or including all in the same regression model, does not change the general results of the baseline NHTSA regression model: that mass reduction is associated with an increase in crash frequency in all three types of vehicles, while footprint reduction is associated with an increase in crash frequency in cars and light trucks, but with a decrease in crash frequency in CUVs/minivans. The variable with the biggest effect is initial vehicle purchase price, which dramatically reduces the estimated increase in crash frequency in heavier-than-average cars and light trucks, and all CUVs/minivans. These results suggest that other, more subtle, differences in vehicles and their drivers account for the unexpected finding that lighter vehicles have higher crash frequencies than heavier vehicles, for all three types of vehicles.

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